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NOISE

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NOISE

There is widespread concern that the noisy environment of modern man not only is distracting but also causes damage to the ear. What are the facts of the matter, and how can noise be brought under control?

by Leo L. Beranek

Mankind seems destined to live in an increasingly noisy environment. The growth of population and the proliferation of machines are steadily raising the noise level, not only in our cities but also in the countryside. More and more we are exposed to a babel of technological noises that disturb our sleep, make conversation difficult, create anxiety and in many cases may result in a permanent impairment of hearing.

Although the noise problem has been widely discussed and studied for many years, it has not yet been dealt with in any thoroughgoing way. In several sectors of our technology, however, it has recently presented itself in an acute form. A crisis was precipitated for a considerable part of U.S. industry by a court decision in the state of New York in 1948. Matthew Slawinski, a drop-forge worker, had filed a claim against his employer for compensation for partial deafness caused by the high noise level in the shop where he worked. Eventually the New York State Court of Appeals upheld his plea that he had suffered an occupational disability (although he was able to continue at full pay as a drop-forge worker), and he was awarded $1,661.25. The decision was soon followed by the filing of hundreds of claims against employers by workers in noisy industries in many other states. Management alarm in these industries—textile mills, drop-forge and metal-fabricating shops, steel mills, metal-container plants and others—rose to near-panic proportions, and a member of the Wisconsin Industrial Commission estimated that the total of claims for occupational loss of hearing in the U.S. might rise to billions of dollars.

Industry was given a reprieve by later judicial elaboration, in New York and elsewhere, of the original ruling. It is now held that to establish a claim a worker must retire from his noisy occupation for some months in order to determine whether or not his hearing loss is permanent. Since most workers do not wish to give up months of wages (or their occupation) for the chancy opportunity to sue for a compensation award, the surge of claims has subsided.

Nevertheless, industry has not entirely recovered from its scare, and other noise sources—notably the rising din of automobile and airplane traffic—are creating active public concern and demands for remedies. It is clear that the basic problem is essentially incurable; noise is an unavoidable price we must pay for a machine civilization. But if we cannot eliminate the noise of modern technology, we can at least control it to minimize its effects. The problem of control has three main aspects: technical, economic and political.

Effects on Hearing

Let us consider first what has been learned about the effects of noise on the human organism. The most obvious effect, of course, is on the hearing organ. Everyone knows that a very loud noise, such as the explosion of a large firecracker, will produce momentary deafness. Permanent hearing loss, however, develops only from repeated or continuous exposure to high noise levels. The relation between such exposure and hearing impairment has been investigated carefully in a number of studies.

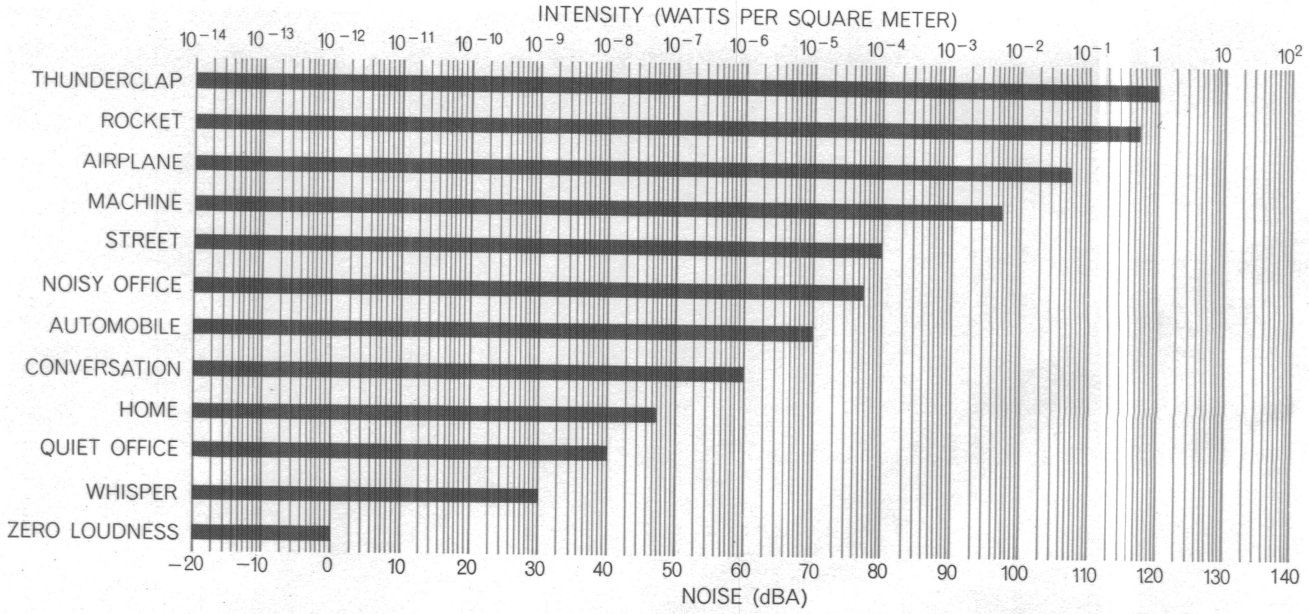
To understand the results of these tests one must know something about the methods of measurement. The intensity of sound is measured in decibels, and a person's hearing is measured in terms of the threshold decibel levels at which his ear can detect sounds at given frequencies. The amount of an individual's "hearing loss" can therefore be gauged by comparing his acuity with an average or standard of hearing sensitivity; if, for instance, a sound must be raised to 15 decibels above the standard for him to hear it, he is said to have suffered a 15-decibel hearing loss. In the U.S. the standard for average hearing has been established by the American Standards Association on the basis of tests of a large group of people between 18 and 30 years of age without hearing difficulties.

As is well known, the audibility and quality of sounds depend a great deal on frequency. The frequencies up to 3,000 cycles per second are the most important for understanding speech. Higher frequencies are generally judged "noisier" and more annoying (although they are essential for full enjoyment of music). It is at the higher frequencies that hearing losses become most marked with advancing age or in the impairment due to exposure to noise. Hearing tests generally examine the subject's sensitivity in a series of bands; each band consists of an octave, that is, the highest frequency in it is twice that of the lowest.

Here are the results of a classic study of 400 men engaged in a noisy occupation. They had worked daily at a noise level averaging 90 decibels in each of the six octave bands between 100 and 6,000 cycles per second, some of them for periods of up to 40 years. On the average the men suffered substantial hearing losses, particularly at the higher frequencies and during the early years of their exposure. Some of those who had been exposed for 10 years, even young men of 30, had so much impairment that they found it difficult to understand speech.

The study showed that individuals differ considerably in their vulnerability

SONIC BOOM, one of the many new noises plaguing man today, is produced when an airplane that is traveling at supersonic speed generates a cone-shaped shock wave such as the one seen in this schlieren photograph. When such a shock wave drags along the ground, it causes an abrupt change in air pressure that may exceed two pounds per square foot. The photograph, which shows a test model of an airplane nose, was made in a high-speed wind tunnel at the research center of the Lockheed Aircraft Corporation.



COMPARATIVE INTENSITIES of a variety of common sounds are arrayed from bottom to top in order of increasing sound pressure, expressed both in "*A*"-scale decibels, or dBA (*bottom scale*), a unit that emphasizes higher frequencies, and in watts (*top scale*).

to noise: among those who had been exposed for 25 years or more there was a spread of about 30 decibels in the amount of hearing loss at the higher frequencies. The variation in vulnerability suggests that it should be possible to discover at a fairly early stage those persons who are particularly susceptible to hearing impairment and transfer them to quieter jobs. The damaging effect of noise is especially marked and prompt in showing itself at the frequency of 4,000 cycles per second; hence this test should be a good indicator for identifying noise-susceptible people. By way of comparison, a separate study of individuals who pursued quiet occupations has shown in detail how hearing at the high frequencies deteriorates with age. Among men in their 60's the average loss of hearing at these frequencies is about 30 decibels, and in the 70's the loss rises to some 40 decibels or more.

Psychological Effects

When we move into other realms of noise effects, such as the psychological consequences, it is hard to find a basis for measurement. The noises of our daily life have been blamed variously for the high divorce rate, social conflict, indigestion and other organic disabilities, nervous breakdown, high blood pressure, heart failure and even insanity. Most of these allegations arise from overvivid imaginations, but one cannot rule out the possibility that some people are particularly sensitive to noise just as others are allergic to nuts, eggs or household dust. As far as controlled social observations go, however, we can only say that the demonstrable and important biological effects of loud noise are—in addition to the impairment of hearing—interference with speech communication, distraction of people from work requiring concentration, interference with sleep and a subjective reaction of annoyance.

Studies of the annoyance effect have been conducted among people living in noisy areas: in central London, near the London airport and in several U.S. cities, some of them near military air bases. Thousands of people were interviewed, and some interesting statistics have emerged. In any noisy environment, whatever the intensity of the noise, about a fourth of the inhabitants say they are not perturbed by the noisy activities. These people apparently are able to live happily next to elevated railroads, trucking routes, airplane flight paths and other loud noise sources. At the other extreme, about a tenth of those interviewed seem to be disturbed by almost any noise not of their own making, regardless of how faint it may be. (The interviews elicited the fact that the same people were dissatisfied with many other things in their environment.)

In areas where a specific source (such as airplanes) produces a constant din, about a third of the people said they tended to get used to the noise; on the other hand, a fourth said they were increasingly bothered by the noise as time went on. Personal reactions to noise did not appear to be correlated to any significant extent with age, sex, income or education. Many people were, however, influenced by specific fears: many of those who lived next to traffic routes said they were sensitive to the noise because of fear for the safety of their children; many of those near airports dreaded the noise because of the possibility of plane crashes. We should not minimize the annoyance effect of noise. Some physiologists assert that annoyance is a biological protective mechanism (like the discomforts of fatigue, hunger or cold) that impels the organism to avoid noise as it does other signals of disturbance.

Noise Control

Let us turn now to what has been done, and what can be done, to control noise in the areas of greatest concern. Foremost among these areas, of course, is industry, where continual exposure may seriously damage the workers' hearing.

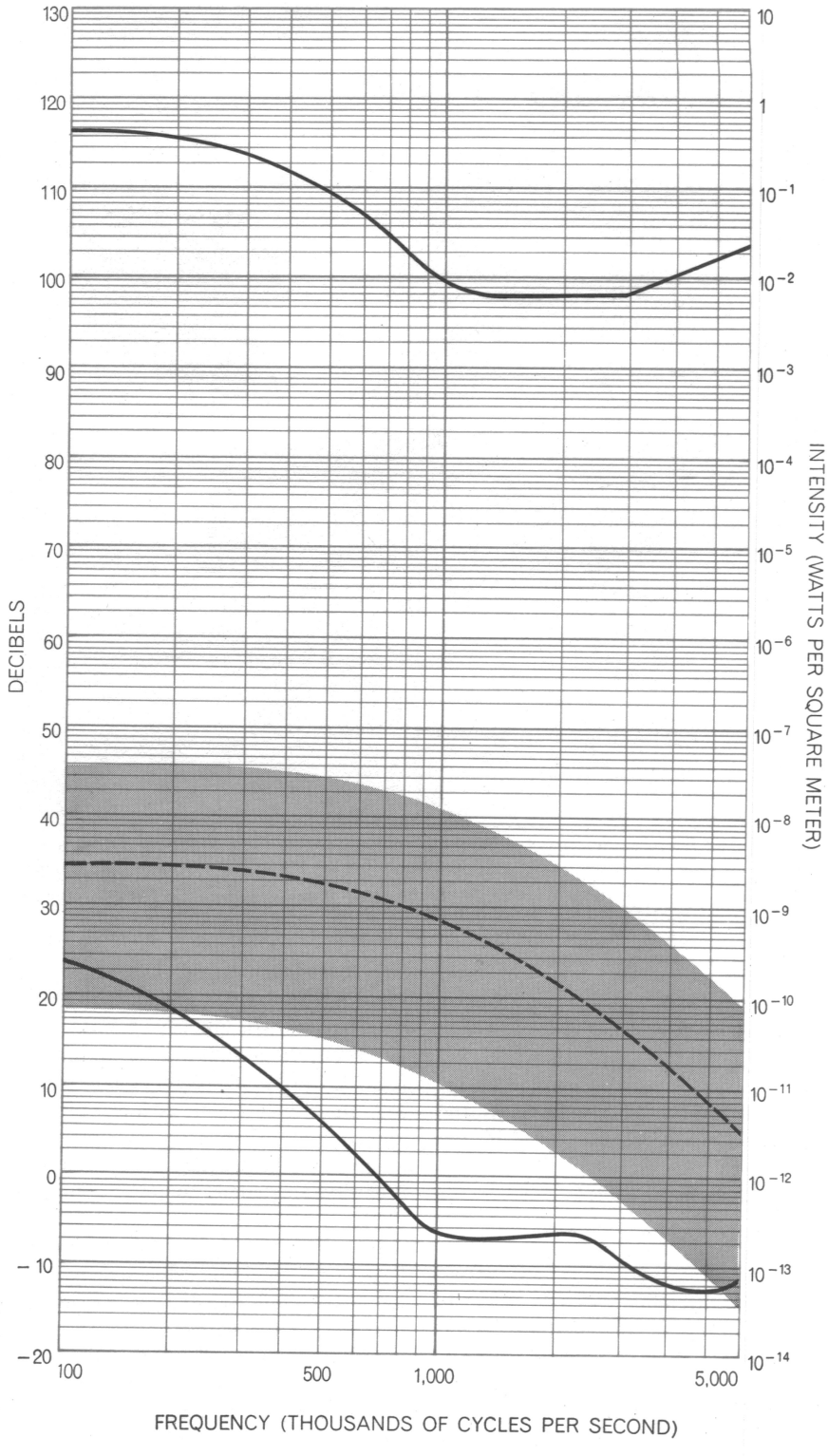
The first need is to determine what the tolerable levels are, and a number of studies have been devoted to this question. A committee of the American Standards Association, in an investigation that is still under way, has arrived at some preliminary ideas on permissible limits of noise exposure for a worker at his daily job. The test applied by the committee is that after 10 years of the daily exposure a worker should not have suffered any appreciable impairment of his ability to understand speech at nor-

mal voice levels. On the basis of this criterion the committee investigators have determined permissible daily "quotas" of exposure, that is, the number of minutes of exposure per day that can be tolerated at various decibel levels and for various sound frequencies. The committee's tentative conclusion is that over an eight-hour working day 85 decibels (for each of the octave-band frequencies above 700 cycles per second) is about the limit people can tolerate without substantial damage to their hearing. A study by the U.S. Navy has suggested that a higher figure is permissible; testing naval personnel, it found that daily exposure up to 90 decibels did not impair the men's ability to understand speech.

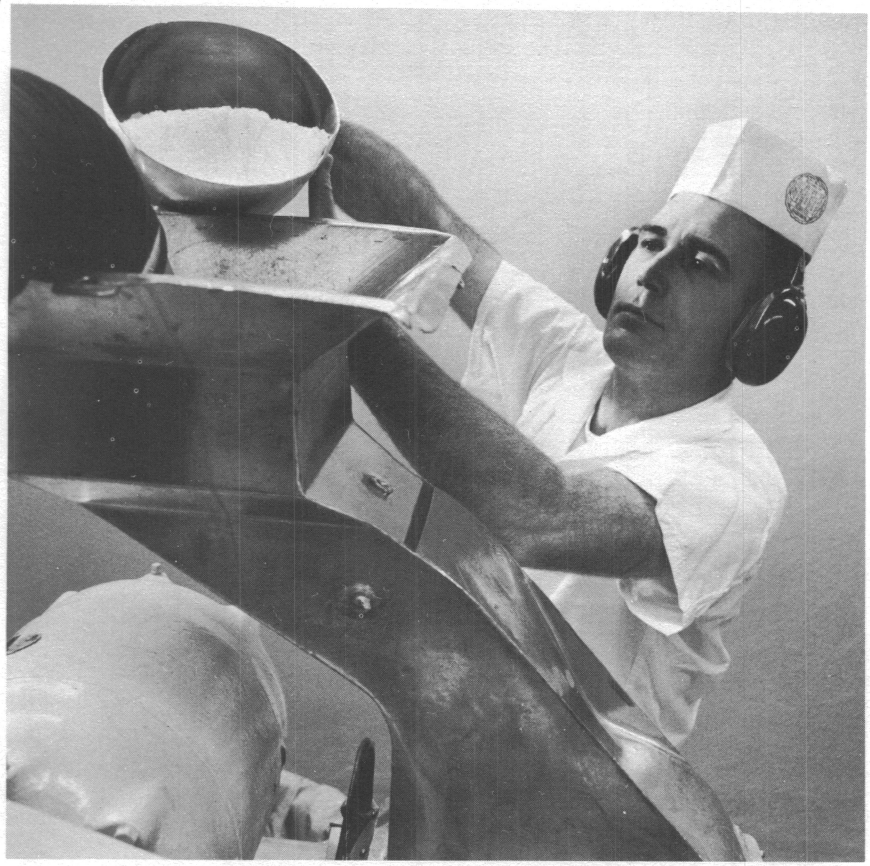
The noisy industries themselves have begun to take steps to reduce the risk of hearing loss. Most of the employers in these industries now test the hearing of workers when they are hired and at intervals afterward. They often require workers in the noisy locations to wear earplugs, earmuffs or both. Many factories are applying mufflers and other noise-reducers to their machines, building enclosures around them and covering the room walls with sound-absorbing materials. Some companies go so far as to specify, when buying new machinery, that the machines must not generate noise above a stated level.

At the political level a few states have adopted legislation requiring employers in noisy plants to provide earplugs or earmuffs for their workers. In California the state Department of Industrial Relations has issued a noise-control safety order specifying the circumstances under which ear protection must be worn. It is required, for example, if the worker is exposed for more than five hours a day to 95 decibels or more in any one of the octave-band frequencies above 300 cycles per second.

A number of states now have laws that give workers the right to claim compensation if they have suffered a loss of ability to understand speech, even though this may not have meant the loss of their jobs. The Council of State Governments has recommended a uniform law for all the states that would specify the conditions for compensation claims. It defines noise-induced hearing loss as a compensable disability and establishes a disability scale based on the average of the hearing loss measured at 500, 1,000 and 2,000 cycles per second. The compensable loss would be that beyond 15 decibels, after deducting the natural loss due simply to aging (which is specified as half a decibel per year after the age of



HUMAN HEARING extends over a considerable range of frequencies and can accommodate to a surprisingly wide range of sound pressures. The sound pressure is measured in decibels, or tenths of a bel (a logarithmic unit used to express ratios). Zero on the decibel scale indicates the barely audible sound produced by a pressure of .0002 microbar (one microbar equals one dyne per square centimeter, or about a millionth of a standard atmosphere) alternating at the rate of 1,000 cycles per second. Sound intensity increases exponentially: a 10-decibel sound is only twice as loud as a one-decibel sound, but a 20-decibel sound is four times louder and a 100-decibel sound is 1,000 times louder. The light gray area includes the range of frequencies and intensities that the normal human voice produces; the broken line dividing this area follows the average speech level for a male standing three feet away. Signals with pressures below the bottom curve are usually inaudible. Signals with pressures above the top curve, in turn, so overload the human ear as to be unintelligible.



EAR COVERS protect a pharmaceutical-plant employee from the 100-decibel din of a pulverizing machine. Hearing protection is recommended for all workers who are consistently exposed to noise louder than 85 decibels in frequency bands above 150 cycles per second.

40). The recommended legislation also includes provisions designed to protect employers: workers could file claims only after six months of separation from exposure to noise and the employer's responsibility would be limited to the amount of hearing loss incurred by the worker with this employer (that is, excluding losses in previous jobs).

Noise and Speech

I want at this point to discuss in a little more detail the loss of the ability to understand speech, to which I have already referred so often in this article. The word-comprehension test has proved to be a remarkably useful aid to noise research, not only because it provides a convenient way to measure hearing loss but also because it serves as a criterion for establishing permissible noise limits in almost all types of situation. The analysis of speech sounds and of effects of noise on speech comprehension has therefore given us invaluable information.

Laboratory studies with sound-recording devices tell us that speech is made up of a great variety of sounds at various frequencies and intensities. Each letter or syllable, as normally enunciated, carries a mixture of tones, each with a certain characteristic intensity. Consider the word "sit." The sound of "s" consists of relatively high-pitched tones at a moderate intensity level; "i" is lower-pitched and stronger in intensity; "t" is made up mainly of high-frequency tones at low intensity, so that its sound is comparatively faint. Now, to understand the word when it is spoken a listener must hear and unambiguously identify each letter. If he fails to catch the "t," he may mistake "sit" for "six"; if he misses the "i" sound, he cannot tell whether the word is "sit" or "sat." Laboratory tests have in fact demonstrated that to understand English speech perfectly one needs to hear essentially all its sounds over the frequency range from 200 to 6,000 cycles per second. It has been found that this spectrum can be divided into some 20 bands, all of which prove to be equally important for speech intelligibility. It also turns out that within each band the intensity of the various speech sounds (for letters and syllables) as they are ordinarily enunciated varies over a range of about 30 decibels (from the faintest to the most intense). We can therefore plot on a graph the region of speech intelligibility, in terms of the necessary decibel levels for the various frequencies.

As a standard for reference we can plot the "speech region" in the case of a young male speaker talking at a normal voice level and standing about three feet from the listener. If the speaker talks softly, the entire speech region moves down about six decibels (that is, all the sounds are that much fainter); if he raises his voice above the normal level, the region rises six decibels above the standard; if he shouts, the region moves up another six decibels. The sound level for the listener also varies with distance between the speaker and the listener: for each doubling of the distance the speech sounds become six decibels fainter, and for each halving of the distance they become six decibels louder.

Now, if we plot on the same graph the threshold levels of audibility of sounds for persons with average or normal hearing, we can readily measure the effects of loss of hearing ability. Whenever a person's hearing loss is such that his audibility threshold rises into the normal speech region, he will fail to hear the speech sounds at the affected frequencies and to that extent will suffer a loss of speech comprehension.

The effects of interfering noise can be shown even more graphically. Noises at decibel levels within the speech region will mask, or blot out, the speech sounds. There are continuous-spectrum noises, such as those of a waterfall, a jet engine or a moving train, that will overwhelm the speech region at all frequencies. Thus a railroad train approaching a station where two persons are talking makes it more and more difficult for the two to understand each other, and at its peak the train noise may make speech impossible. By raising their voices and moving closer together, thereby elevating their speech region, the two speakers may be able to achieve a slight measure of communication. There is a level, however, at which speech can be too loud to be understood. A person shouting into a listener's ear may so overload the ear that the speech sounds become unrecognizable.

From the type of analysis I have been describing we can derive information that enables us to set up definite criteria for noise control in our various working and living spaces: offices, conference rooms, shops, homes and outdoor locations. In our laboratory at Bolt, Beranek and Newman, Inc., we have worked out a scale of speech-interference level (SIL) that can be used as a guide for determining the permissible limits of background

noise in given situations. The scale defines background noise in terms of a kind of decibel specially created for the purpose: the SILdB. This unit is an average of the decibel readings in the three octave bands between 600 and 4,800 cycles per second. For instance, in the case of two persons six feet apart outdoors, one speaker will readily make himself understood by speaking in a normal voice if the interfering noise level is no louder than 49 SILdB; against a background of 55 SILdB he will have to raise his voice; at 67 SILdB he must shout.

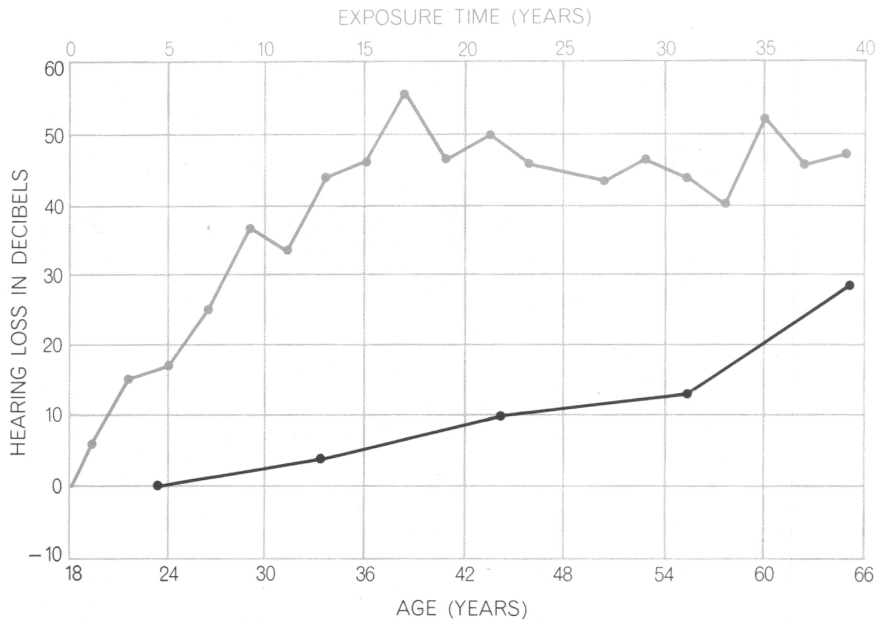
Using this scale, we have derived the following criteria for specific situations. In a private office or small conference room, where the people may be separated by distances of 10 to 25 feet, the speech-interference level of the background noise should be no higher than 30 to 35 SILdB, so that conversation can be carried on at normal voice levels. In large engineering and drafting rooms, where people may stand closer together (about six feet apart) and be willing to raise their voices, a noise level of 40 to 50 SILdB is tolerable. In the home, if we apply a standard of quietness that would allow the television or radio to be understood comfortably at moderate levels of loudness, the interfering noise level should be no more than 30 to 35 SILdB. For telephone conversation the interfering noise should be no more than 45 SILdB; above that level background noise begins to make telephone communication difficult, and when it reaches 75 SILdB use of the telephone may become impossible. In all situations the highest noise level that will allow any intelligible communication is about 90 SILdB; against this background the speaker must shout into the listener's ear from a distance of three to six inches.

Quieter Buildings

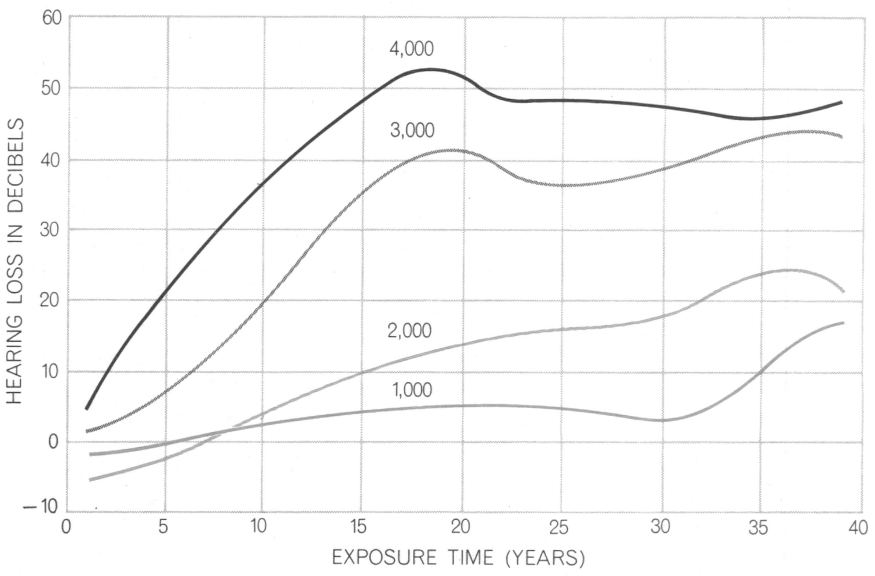
What can be done to make our buildings, particularly dwellings, quieter? Certainly we must give more thought to their basic design. In contemporary architecture the primary emphasis seems to be not on function but on aesthetics. Two of the principal ideals are transparency and continuity—in physical terms, glass and the open plan. Unfortunately continuous structures and open plans are inimical to quiet living. Many modern dwellings are acoustical torture chambers!

In apartment buildings the errors of design are compounded by economic pressures that have resulted in a too flimsy separation between apartments. Many new high-rise apartment buildings in New York are so noisy that their occupancy rates have fallen below the profitable level. Apartment hunters have been known to carry portable radios with them so that they can test the noise transfer from one apartment to the next. Some owners of cooperative apartments are compelled to spend large sums to insulate their dwellings more satisfactorily against the noise of their neighbors.

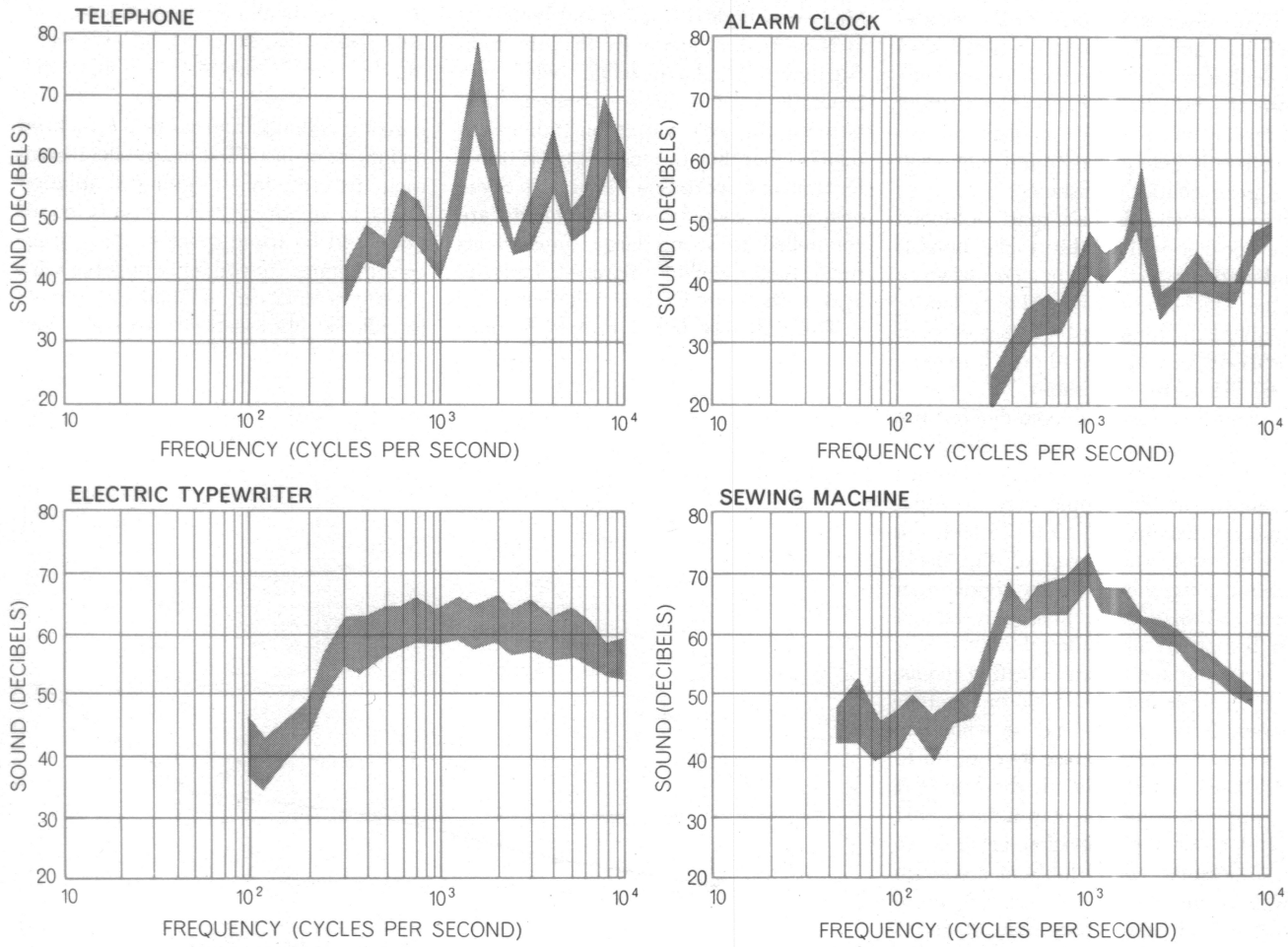
The difficulty is not that techniques for making dwellings quiet are unavailable. Noise can be controlled by erecting heavier or multilayered walls between apartments, by floating floors or hanging ceilings from vertical structural members, by installing nearly silent bathroom fixtures, by designing ventilation ducts to minimize the transmission of noise and by using quiet systems of air conditioning. Indeed, it is possible with present techniques to build apartments (or offices, libraries and hospitals) that



LOSS OF HEARING is a natural result of aging (*bottom curve and scale*), but a much more severe loss can result from exposure to an excessively noisy environment (*top curve and scale*). High-frequency hearing suffers the most. Both curves are for 4,000 cycles per second.



CUMULATIVE DEAFNESS, due to years of exposure to a noise level averaging 90 decibels in each frequency band, shows two peaks. The maximum hearing loss at frequencies of 3,000 cycles per second and above is reached in about 15 years. Loss of hearing at frequencies of 2,000 cycles and below, however, does not reach its maximum until after 30 years or more.



INTENSITY OF COMMON NOISES at various frequencies is demonstrated for the bells of a telephone and an alarm clock and the various moving parts of an electric typewriter and a sewing machine. The most intense noise of all is one peak (between 1,000 and 2,000 cycles per second) of the telephone bell: it reached 76 decibels at the loud setting. The bell of the alarm clock shows five peaks of noise, as does the telephone bell, and one of these is higher in frequency. The typewriter proves to be uniform in noise level over most of its range. The sewing machine rivals the telephone bell in sound pressure and outdoes it in range. Ray Donley of Goodfriend-Ostergaard Associates in Cedar Knolls, N.J., recorded the noises and made the sound-pressure analyses shown here.

are actually too quiet—so silent that even faint noises from outside become obtrusive and disturbing. In that case there is a simple and pleasant remedy: one can introduce a gentle, steady, "white" noise —a noise "perfume" that masks the intrusive noises and has a soothing effect.

In Europe long experience in apartment living and a popular taste for gracious living (in preference to gadgets) have led to careful attention to noise control in the construction of multiple-family dwellings. Britain, the Netherlands, Germany, Sweden and the U.S.S.R. have well-developed acoustical building codes that have been applied to the large-scale program of the rebuilding of housing since World War II.

Studies have shown that the noises apartment dwellers consider most annoying are radio or television noise from neighboring apartments and impact noises, as from people moving about on the floor above. It is not possible to achieve accurate control of the transmission of such noises simply by specifying construction requirements for walls and floors, because noise can travel from one room to another along continuous walls and through cracks, ventilation ducts, electric boxes, pipes, conduits or medicine cabinets. Therefore the codes focus on specifying limits for the amount of noise that may be transmitted, leaving it to the builders to devise means of complying with these limits. The amount of transmission is tested by devices such as a pounding machine that hammers on a floor so that the reception of noise in a room below can be measured. A general formula for rating the insulating value of floors, ceilings and walls has been devised: it is based on the difference in noise level (at 16 significant frequencies) between the room where the noise originates and the one where it is received.

The Netherlands code specifies, for example, that a loud noise must be so muffled that the noise level at 2,000 cycles per second is 54 decibels lower in the receiving room. (Less attenuation of noise is required, however, at lower frequencies.) In Britain, which has separate standards for Grade I and Grade II (less expensive) structures, the minimum absorption requirements for noise at 2,000 cycles per second are 56 and 51 decibels respectively.

In the U.S. such codes are entirely lacking, and only New York is seriously considering one. A proposed code for that city would set the insulation requirement (at 2,000 cycles per second) at 45 decibels—six decibels less satisfactory than even the Grade II code in Britain. Even so, the proposed New York standard would be an improvement over present conditions there. In many of its present apartment buildings the noise insulation is 10 or more decibels worse than the proposed code.

The control of apartment noise in the U.S. will be a most difficult matter. Building codes are strictly local; each of the nation's 6,000 cities and towns writes

its own code. Labor is slow to accept new building techniques. Builders, under the pressure of competition, are governed primarily by economic considerations. Many argue that to attain in the U.S. the standards of quietness now enjoyed in modern apartments in Europe (where building costs are much lower) would require the development of new types of lightweight apartment structures that would be cheaper to build in terms of materials and labor costs.

Nevertheless, it seems that the time is near when we can expect noise-control codes throughout the nation. The Federal Housing Administration is supporting a comprehensive study of the control of noise in multiunit dwellings. This study may in time lead to Federal noise-control requirements for housing built under FHA mortgages. Moreover, if New York adopts a noise code, other cities undoubtedly will follow its lead. It seems likely that public demand, expressing itself through codes and in the marketplace through a deliberate search for quiet in apartment-hunting, will compel increasing attention to noise control in apartment construction. Among other things, it should stimulate research on reducing the cost of building quiet into our dwellings.

Vehicular Noise

We consider next the noise of our vehicles. In retrospect the clip-clop of horses and the rumbling of carriages seem the sounds of an idyllic way of life. Our drive to be continually on the move and to travel ever more rapidly has created a noise nuisance that already has reached awesome proportions and becomes increasingly difficult to live with. In a British government survey of residents of central London, in which some 1,400 people were questioned, traffic noise stood at the top of the list of things in the environment that people would most like to change. The din of motor-vehicle traffic was considered more annoying than all other noises put together; four to seven times as many people were disturbed by this noise as by the noise of airplanes, trains or industry.

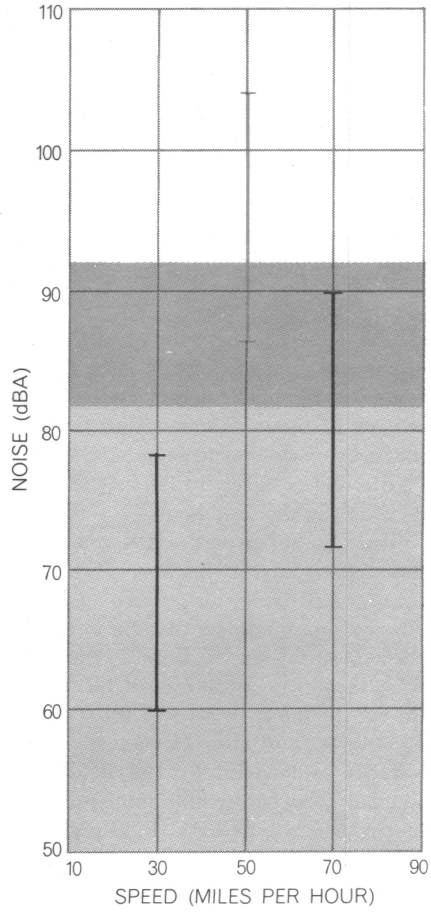
It is abundantly clear, therefore, that if city living is to be made tolerably quiet, the first efforts must be directed to reducing the noise of motor traffic. We cannot banish the automobiles, buses and trucks; they are a necessary part of our lives. It does not follow, however, that we must put up with all the noise now created by these machines.

The levels of noise produced by various types of motor vehicle have been measured carefully on the basis of their irritating effect on hearers. This measure depends not only on the physical energy of the noise but also on the hearer's perception of its loudness, or "noisiness." Noise-measuring instruments have a standard setting—the "*A*" scale—that gives extra weight to the higher frequencies; these variations in sound pressure are recorded in special units called dBA. Using the *A* scale, a study of motor traffic on California freeways showed that the noisiness level of passenger cars (for a hearer nearby) ranges from about 60 to 78 dBA at 30 miles per hour and rises to about 72 to 90 dBA at 70 miles per hour. The wide spread is due to the fact that old cars, with their worn mufflers, are considerably noisier than new ones. The study showed in quantitative terms that the main noisemakers on the freeways are trucks, buses, motorcycles and sports cars. The average truck at 60 miles per hour is about twice as noisy as a steady stream of passenger-car traffic, and its noise may be well above 100 dBA. The irritating effect of these vehicles is heightened by the startling impact of their loud bursts of noise as they arrive at unpredictable intervals in the traffic stream.

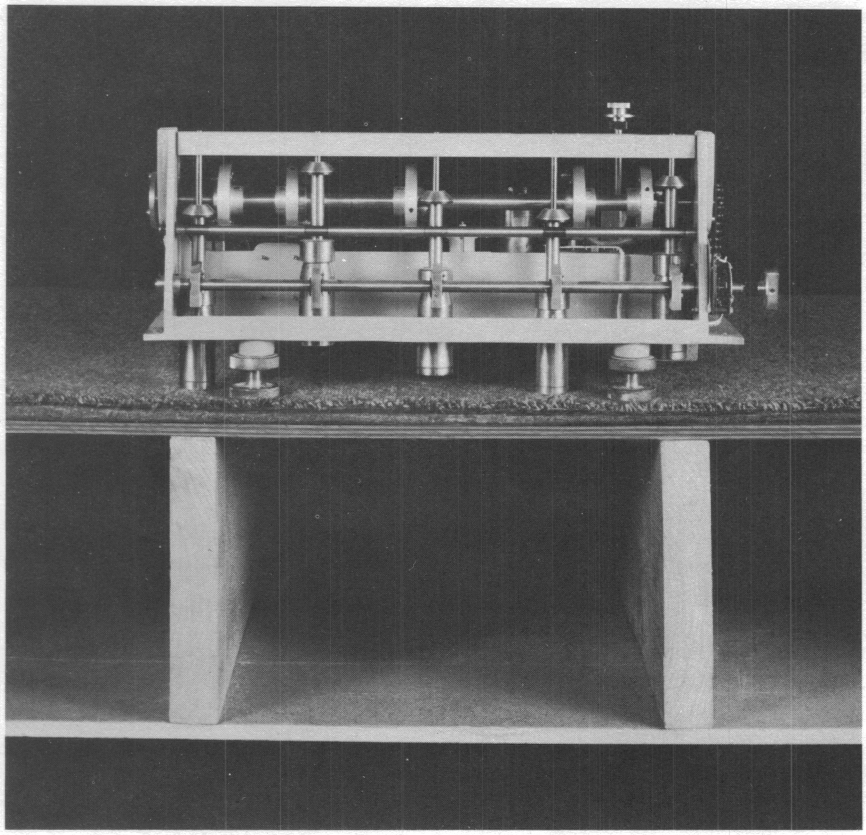
The state of California is considering legislation that would prohibit noise levels above 82 dBA for passenger cars and 92 dBA for trucks and buses. In Britain the national government proposes to limit the maximum permissible noise to 85 dBA for passenger cars and trucks and 90 dBA for motorcycles and other two-wheeled vehicles. France has already established limits of 83 dBA for passenger cars and small trucks, 86 dBA for motorcycles and 90 dBA for large trucks and buses.

It must be said that leaving the problem to state and local legislation in the U.S. would not be effective. So much motor traffic, particularly trucking, is interstate today that national laws are plainly called for. Motor-vehicle noise is one form of hubbub that should not be too difficult to control. Highway builders today have available materials for producing quiet road surfaces. The latest passenger cars generally have effective mufflers and quiet tire treads. Trucks can be equipped with adequate mufflers and noise-damping housing for their engines. We can have quieter as well as safer vehicles.

What can be done about airplane noise? There is no doubt that we shall soon be exposed to a greatly increased volume of noise from this source as air traffic and airports multiply, helicopters become more widely used and supersonic airplanes usher in an era of sonic booms. It is difficult to determine what the tolerable levels of airplane noise are, because they vary widely among individuals and are conditioned by people's attitudes, such as their fear of crashes, their feelings on the subject of whether or not the airlines and airports are concerned about their welfare, and so forth. My own interpretation of the studies that have been made among people living near airports is that for most people the noise begins to become unbearably annoying when the airplane noise peaks (in 20 to 40 daytime flyovers per day) exceed a "perceived noise" level (measured in another special unit) around 115 PNdB. Annoyance rises (or toler-



AUTOMOBILES on a California throughway make noises heard at a distance of 25 feet with the indicated range of intensities. Cars moving at 70 miles per hour are from two to four times noisier than at 30 miles per hour. At 50 miles per hour trucks (*color*) were as noisy as planes at takeoff. The colored blocks mark the maximum allowable noise levels proposed by highway officials for cars (*light*) and trucks (*dark*).



POUNDING MACHINE is used to determine the amount of insulation against impact noise that is provided by floor-ceiling construction in multiple dwellings. Each of its hammers weighs 1.1 pounds; they fall 1.6 inches in succession and deliver 10 impacts per second.

ance declines) if the number of flyovers or the duration of noise in each flyover is increased, and tolerance also drops sharply at night. Some studies indicate that a flyover seems to sound 10 or more PNdB noisier after 10:00 P.M. than it does during daytime hours.

The London airport and Kennedy International Airport in New York have set up noise limits for jet airplane takeoffs (but not landings) that are in accord with these figures. In London the takeoff is supposed not to exceed 110 PNdB during the hours between 7:00 A.M. and 11:00 P.M., and after 11:00 P.M. the allowance is lowered to 102 PNdB. At Kennedy the permissible limit for takeoffs over land is 112 PNdB; at night the jets are usually required to take off over water.

The Federal Aviation Agency, which operates the Washington National Airport, has been experimenting with takeoff patterns designed to minimize noise in the surrounding residential areas. Jet airplanes are required to climb as steeply as possible to an altitude of about 1,500 feet and then coast on minimal power up to 3,000 feet. To avoid flying directly over houses in the early part of the takeoff the plane is also required to follow the Potomac River as it climbs.

For the noisy landings of jet airplanes, made particularly irritating by the whine of their engine-intake compressors, ameliorating maneuvers are not yet feasible. Most pilots believe for safety's sake they must come in to the landing strip at a low glide angle. To approach at a steeper angle—say six or eight degrees instead of three degrees—would require, they insist, several improvements in airplane design: better instrumentation (perhaps computer control of the landing), better engine response and better plane-handling qualities.

Many things could be done to design airplanes for less noisy operation. Prompted by regulations of the Port of New York Authority, operator of Kennedy and other airports, airplane manufacturers have fitted silencing devices to the exhaust ports of turbojet engines. The new turbofan type of engine has increased thrust greatly without a proportional increase in noise (but unfortunately it cannot be quieted appreciably by silencers). Some manufacturers of jet airplanes are studying the possibility of mounting the engine nacelles above instead of under the wings, so that the wings will prevent much of the noise from reaching the ground. Designers can also think of ways to control noises by modifications of the engines, nacelles and wings, and it is believed refinements of design would allow airplanes to climb and land at steeper angles. These cost-incurring antinoise improvements are not likely to be undertaken, however, until the Federal Aviation Agency forces their adoption by spelling out limits on the noise that will be tolerated from new airplanes.

Supersonic-Airplane Noise

Ahead of us lies the prospect of sonic booms from the next generation of airplanes—the supersonic transport (SST). The coming of supersonic travel is inevitable; we must prepare to control its effects. The tests that have been conducted so far suggest that sonic booms need not be destructive and that people may be more apprehensive about the phenomenon than they need to be.

When an airplane moves faster than the speed of sound, it produces shock waves that trail in the wake of the plane like the disturbances in the water wake of a rapidly moving boat. The shock waves generate a pressure wave that constitutes the sonic boom. On the ground a typical sonic boom from a high-flying airplane represents a series of rapid changes in air pressure lasting half a second: the pressure suddenly rises by as much as two pounds per square foot, then drops below atmospheric pressure by about the same amount and finally jumps back to normal pressure. The noise of the boom usually consists of two closely spaced, explosive reports.

The sonic-boom "wake" behind the airplane, fanning out in the shape of a cone, spans an area on the earth below that depends on the height at which the plane is flying. Typically the path of the boom on the ground is about 33 miles wide when the plane is at an altitude of three and a half miles and 50 miles wide when it is flying at a height of nine miles. The higher the plane flies, the weaker is the intensity of the boom at the ground.

The U.S. Government has conducted a number of studies of the effects of sonic booms, the most elaborate of which was a six-month test, from February to July of 1964, in the Oklahoma City area. The area was subjected to a total of 1,250 sonic booms from airplanes (during daytime hours). The average intensity of the booms in the early weeks of the test was 1.13 pounds per square foot and eventually it was raised to 1.6 pounds per square foot. Samplings of the

public reaction showed that most of the people living within eight miles of the center line of a boom path were disturbed by the sonic booms. About a fourth of the people interviewed at the end of the six-month trial said that eight booms a day at the intensity of 1.6 pounds per square foot was more than they could learn to accept.

It appears that the main source of complaint was fear of damage to structures—cracks in plaster walls, weakening of the construction and so forth. More than 40 percent of the people interviewed in Oklahoma City believed their homes had been damaged by the sonic booms. Yet careful surveys of many houses showed no visible evidence of damage. In areas of the country where military airplanes regularly carry out supersonic flights, often producing strong sonic booms of more than two pounds per square foot, few damage claims have been filed by residents. On the whole the available evidence suggests that public apprehensiveness about sonic booms will be greatly reduced if people receive credible guarantees that their homes will not be damaged within specified limits of exposure and if these limits are strictly enforced. It is important, therefore, that the Federal Government prepare for the arrival of supersonic travel by establishing tolerable limits for sonic booms—limits that will not damage property or be seriously disturbing to people's peace of mind.

For man in the present "advanced" stage of civilization noise is no longer a trivial problem. It is ironic that the U.S., with its genius for creating technical marvels and solving technological problems, allows this most unpleasant affliction to debase its culture. We could improve the quality of our environment enormously by allocating a portion of our energy and wealth to controlling noise. With some ingenuity and at moderate cost we can hush our noisiest industries to save the hearing of workers. We can mitigate the roar of traffic—on the ground and in the air—by instituting and enforcing noise codes, by improving the design and operation of vehicles, interposing buffer zones to separate residential areas from airports and superhighways (through zoning and condemnation) and by sealing buildings against noise where proximity to noise is unavoidable. With a willingness to pay the extra price in construction costs we can also have quiet homes. It appears that we shall have to pay these costs if we are to make a tolerable adaptation to the noises of civilization.

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